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Auction-based cooperation mechanism to parts scheduling for flexible job shop with inter-cells

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ABSTRACT

This paper addresses cell part scheduling (CPS) problem. In this problem, parts may need to visit machines in different cells with consideration Inter-cell transportation time. The processing route of parts can be flexible. The objective is to minimize the overall process make-span. An integer nonlinear programming (INLP) model is formulated to determine the schedule scheme of all parts. An auction-based heuristic approach is proposed to solve it, which focuses on dealing with cooperation between different cells. In this approach, each cell can act as an auctioneer or a bidder. In an auction, it contains call for auction, bid construction, modify bids and winner announcement. A reference matrix is also applied in the auction to guarantee parts to finish as early as possible. Numerical experiments were conducted to test the auction-based approach. The results demonstrate the effectiveness, sensitivity and stability of the proposed auction-based approach, especially suitable for instances in large scale within a short calculating time.

1. Introduction

Cellular manufacturing (CM) is a production system in which the parts requiring similar production process are grouped in distinct manufacturing cells [27]. CM has been broadly applied in small-to-medium lot productions of highly customized and complex products [19]. The major advantages of cell manufacturing system (CMS) have been reported in the literature, such as reduction in setup time, throughput time, work-in-process inventories, material handling cost and better in flexibility [30,12,13].

Implementing a CMS consists of two steps. The first step is cell design, which includes cell formation (CF) and cell layout (CL). The second is cell part scheduling (CPS). CPS problem deals with the allocation of manufacturing resources to handle a collection of parts in cells, and it is a decision-making process that plays an important role in CMS [30].

The exist study in CMS can be categorized into two according to the number of cells: single-cell part scheduling(S-CPS) and multi-cell part scheduling (M-CPS).M-CPS has received less attention than S-CPS, just from a few researchers [27,30,10]. Solimanpur et al. [27] proposed a two-stage algorithm, termed as intra-cell scheduling and inter-cell scheduling, determining the sequence of parts within manufacturing cells and the sequence of cells respectively, named SVS-algorithm to solve the scheduling of manufacturing cells in which parts may need to visit different cells. Tang et al. [30] proposed a scatter search approach, which redesigns the common components of scatter search and incorporates diversification generation method, local search method and other improvement mechanisms to provide a wide exploration of the search space through intensification and diversification, to address M-CPS problem with exceptional parts processed on machines located in multiple cells. Tavakkoli-Moghaddam et al. [31] developed a meta-heuristic algorithm based on the scatter search, regarding four criteria to resolve the scheduling problem, to solve the same problem as Tang et al. [30] with the objective of minimizing the intra-cell movements of parts, makespan, tardiness, and sequence-dependent setup cost simultaneously. Elmi et al. [10] proposed a simulated annealing containing a neighborhood structure based on the concept of blocks, also to solve the same problem as Tang et al. [30] with additional assumption that reentrant parts which need to visit some machines more than once in non-consecutive manner. Lin et al. [19] developed an effective multi- start simulated annealing (MSA) heuristic, combining the respective advantages of the multi-start hill climbing strategy and simulated annealing, to minimize the make-span for a flow-line manufacturing cell scheduling problem with sequence dependent family setup times, evaluated the effectiveness and efficiency by comparing its performance against the state-of-the-art meta-heuristics. Bouabda

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et al. [5] developed a cooperative approach including a genetic algorithm and a branch and bound procedure to address the permutation flowline manufacturing cell with sequence dependent family setup times problem with the objective to minimize the make-span criterion. The application of the branch and bound algorithm is based upon the decomposition of the problem into sub-problems. Li et al. [17] proposed a combinational ant colony optimization (CACO) approach to address a cellular manufacturing system with inter-cell scheduling and setup time, designed two structures for the single-processing machines and one batch-processing machine respectively. The single-batch model and the batch-single model are proposed and integrated into a complete one. Zeng et al. [37] addressed part scheduling problems (CPS problems) in the context of the need for exceptional parts to visit machines among cells and to be transferred via an automated guided vehicle (AGV) in order to minimize the process make-span by a two stage heuristic algorithm, consisting of a local search combined genetic algorithm based on the disjunctive graph model and a heuristic algorithm on the purpose to take a lower make-span by roulette, to solve the Intra-cell part scheduling (Intra-CPS) and the Inter-CPS respectively similar to Solimanpur et al. [27]. Compared to classical flow shop and job shop or S-CPS, the key (difficult) problem of M-CPS is how to cooperate between different cells. However, the existing solution methods for M-CPS are just intelligent heuristic algorithms. Still there is a lack of mature mechanism at this point.

Auctions are important market mechanisms used since the earliest of times for the allocation of goods and services [23]. Auctions are used for products when price depends on supply and demand at a specific moment in time or sellers do not know the price of the product [14]. The most common kind of auctions is bid-auction where buyers submit bids and sellers then decide to announce a winner or not. Many auctions involves a variety of distinct assets, bidders have preferences for a set of items, such type of auctions are known as combinatorial auctions which are NP-hard problems [35]. Nowadays auction theory has been used in many fields: such as in electricity by [11], in supply chain by Chen et al. [6], in chemical by Reisch [24], in transportation by Robu et al. [22] and in wireless network by Baidas and MacKenzie [3]. For manufacturing scheduling, auction theory also has been successfully applied. In a manufacturing environment, machines also act as auctioneers (sellers) and jobs act as bidders [8]. Bids are typically computed as functions of job or machine data [9]. Dewan and Joshi [8] presented the details of distributed implementation for new auction-based distributed scheduling mechanism for a job shop that can be used for a wide range of objectives. The auction model implemented uses a job-machine decomposition with each machine being an auctioneer and the jobs being bidders in the auction. The job and machine sub-problems, along with bids and the bid evaluation scheme, are mathematically structured to ensure a predictable system performance. Dewan and Joshi [9] presented a new job shop formulation, maintaining a linear objective function even when the objective is to minimize squared or higher order deviations from the due date, which schedules jobs using auctions for distributing control. Lagrangian Relaxation is used for problem decomposition, bid construction, and bid evaluation for the auction using standard mathematical programming tools. Srivinas et al. [29] employed the methodology of winner determination using the combinatorial auction process, along with different bidding rules, to solve the flexible manufacturing system machine-loading problem where job selection and operation allocation on machines are to be performed such that there is a minimization of system unbalance and a maximization of throughput. In the combinatorial auction, allowing bidding on a combination of assets offers a way to enhance the efficiency of allocating the assets. Attanasio et al. [2] presented a preliminary study which aims at developing auctions mechanisms for decentralized scheduling parallel machines scheduling which exhibit minimal communication overhead and an efficient usage of resources, showing the strong links between auction and Lagrangian-based decomposition, describing and testing different versions of the auction mechanism in case of independent jobs on parallel machines. Veeramani and Wang [32] addressed an auction-based fully-distributed manufacturing system, applied a novel bid construction scheme to the planning and control of manufacturing activities, also proposed the optimal sequencing theory to develop a dynamic programming (DP)–based bid construction algorithm, utilizing parallel and distributed computing technology to model and implement the auction-based manufacturing control system to gain further insights into the effectiveness. Omori et al. [21] proposed a scheduling method with combinatorial auction for cell manufacturing system, analyzed the relationship between optimality and calculation time by comparing with combinatorial auction that searches optimal solution. Adhau et al. [1] proposed a novel distributed multi-agent system using auctions based negotiation approach for resolving the resource conflicts and allocating multiple different types of shared resources amongst multiple competing projects. In proposed approach, the multi-unit combinatorial auction is applied and winner determination problem is solved by efficient new heuristic. The proposed approach can solve complex large-sized multi-project instances without regarding the number of activities, shared resources or the number of projects.

Until now, there has been no reported research applying auction theory to M-CPS problems. In M-CPS problem, each cell wants to maximize its own profit. By auction each cell can evaluate the price properly and sell the good to the bidder with the highest bidding price. The price of bid reflects the degree of demand for the resource. The higher price bidder bids, the more thirsty bidder demands for the resource. Through auction, the resource can be allocated to cells (bidder) with the most urgent need. This allocation mechanism can improve the utilization of the resources. So auction theory would be an appropriate and effective theory to deal with M-CPS problem. In this paper, we address the M-CPS problem the same as [30] along with existing flexible processing route with the objective of minimizing make-span. Firstly, we make elements in auction correspondence to that in manufacturing scheduling, describe how different cells cooperate with each other through auction, and make the scheduling into a auction model. Secondly, we propose an auction-based approach, which is a heuristic algorithm base on auction mechanism to solve the model. The contributions of this paper include the following aspects: (1) An INLP mathematical model is proposed to formulate the problem and an auction-based approach containing an auction based model and an auction-bid approach is designed, which focus on dealing with how to cooperate between different cells. Each cell can act as an auctioneer or a bidder in an auction. The relations between cells in auction are shown in Fig. 1.

In an auction, it contains call for auction, bid construction, modify bids and winner announcement. Each cell can bid for time slots on machines in other cells to process its own parts. A reference matrix is also applied in the auction to guarantee parts to finish as early as possible. (2) A series of test problems are generated to demonstrate the efficiency of the proposed auction-based approach. The solution obtained by the proposed auction-based approach is compared with the global and local optimal values obtained by LINGO 11.0 based on the INLP mathematical model for these test problems, also compared with solutions obtained by the two stage genetic algorithm (GA) proposed by Zeng et al. [37], tabu search (TS) proposed by Solimanpur and Elmi [26] and scatter search (SS) proposed by Tang et al. [30]. The results show the effectiveness, sensitivity and stability of the proposed auction-based approach.